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AN AIRBORNE ZERO-ZERO LANDING LABORATORY

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SUMMARY

This paper describes a flying laboratory with which Ames Research Center will conduct research on zero-zero landing systems. The aircraft which will be remodeled for this purpose is a Convair 340. It will be used to evaluate, under actual flight conditions, advanced state-of-the-art position sensors and display devices. The system with which this aircraft will be landed under zero visibility conditions has been designed specifically for research tasks on zero-zero landing, and has:

(1) The flexibility necessary for research in this area;

(2) The position sensing equipment needed to check out position sensors for airborne zero-zero landing systems. AUTHOR

INTRODUCTION

One form of a zero-zero landing system which has been proposed is airborne and requires minimum ground support equipment. This concept allows the use of smaller landing fields which cannot support large elaborate ILS installations and particularly benefits the short-haul cargo transport operation and commuter aircraft presently confined to VFR landings at airports with limited facilities. It would also have specific applications for military transport aircraft which have to land at remote airfields under all-weather landing conditions.

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The interest at Ames Research Center in systems for zero-zero landing grew out of simulation studies on a display for landing a manually piloted aircraft under zero-zero visibility conditions. In these studies, which were directed toward STOL aircraft, the pilot was an integral part of the control loop. A display with which the pilot could land the aircraft in a simulated environment was conceived. The results of the study were reported in reference 1.

The simulation of zero-zero landing was based on extensive experience at Ames in matching simulated and real-world environments to achieve a useful result. This was done by carefully examining those factors important in the real environment which are required for accurate VFR landings, and extrapolating to generate a display which enables zero-zero landing to be effected in exactly the same manner as the VFR landing. It was determined that it is possible to replace the pilot's view of the outside world in a way to provide him with information sufficiently similar to VFR that his decisions in zero-zero landing are compatible with VFR conditions. A simulator study was carried out as illustrated in figure 1. The inputs to the display were obtained from an analog simulation of landing. The inputs to the analog simulation were from the pilot's visual interpretation of the display. The display developed in the simulation studies is shown in figure 1. Based on opinions of test pilots who have flown the simulator, it was concluded that it is possible to land an actual aircraft under zero-zero conditions with this display. This first phase of the study (reported in ref. 1) was carried out without concern for the system that generated the display. This was possible because in a simulation study the quantities required to generate a display are computed, and it is not necessary to specify system components.

The study of an airborne zero-zero landing system should take into account the components which sense the position of the aircraft and should convey this information to the pilot. These components are the sensing, computing, and display elements. The over-all system requirements and accuracy figures can be estimated from the previously mentioned simulation study, and from Ames engineering test pilot experience in VFR and ILS landings. The simulator study also defined a method of generating the display and the physical quantities defining the aircraft position from which the inputs to the display were computed. On the basis of these studies it appears worthwhile to obtain information that can be used by designers of systems which (fig. 2):

(1) Permit zero-zero landing with minimum ground equipment;

(2) Use displays of the types derived in the simulation studies and discussed in references 1, 2, and 3.

The results of the simulation study made at Ames on a display for zero-zero landing serves as a starting point for studying system concepts for landing an actual aircraft. In addition to defining the display and the system requirements, the simulation study indicated the following accuracy limits for aircraft position (fig. 3): an accuracy of ±500 feet in range at touchdown (this is allowed to increase to 10 percent of the total range when the range is greater than 5000 feet); an accuracy of ±25 feet in lateral displacement at touchdown (this is allowed to increase to 1 percent of the slant range from touchdown when the range value is greater than 2500 feet); an accuracy of ±5 feet in altitude. This is consistent with a glide slope of 0.5° during final approach, and a range error of 500 feet. This error is allowed to increase to 1 percent of the total altitude when this altitude is greater than 500 feet.

It appears that to carry these studies further, it is essential to replace the simulated environment with actual flight conditions. The remainder of this paper will describe the flying laboratory which will be used to continue the Ames studies of zero-zero landing.

DESCRIPTION OF THE ZERO-ZERO LANDING LABORATORY

From simulation studies it has been determined that in a flying laboratory for studying zero-zero landing the following should be considered (fig. 4):

(1) A device for measuring accurately the position of the aircraft relative to the landing strip;

(2) A device for measuring the attitude of the aircraft;

(3) A computer which, from the information obtained by the equipment outlined in (1) and (2), can compute the position of the runway and shape the figures required for the display;

(4) A device to generate the figures for the display;

(5) A display to convey information on aircraft position and attitude to the pilot;

(6) The pilot, who is an integral part of the control loop;

(7) The aircraft, which will be an STOL configuration.

The following interfaces must receive close consideration to assure compatibility of the components into a workable system:

(1) The interface between the position and attitude sensing equipment and the computer;

(2) The interface between the computer and the display to the pilot.

The first phase of the research study will be an evaluation of the system independent of pilot opinion. It is extremely important to determine which pilot opinions stem from improper performance, which are important to consider in system parameter changes, and which indicate differences between the actual and simulated system performance. During the investigations, the correctness of the inputs to the display will be verified. Thus, if the pilot finds the system performance is unsatisfactory, the reason can be determined; that is, whether it is due to error in runway position computation, of if some parameter or concept change is required. A more detailed block diagram of the landing system is shown in figure 5. This diagram breaks the system down into its component parts. After careful consideration of existing sensors, Distance Measuring Equipment (DME) was chosen to obtain aircraft position. The systems considered were radar, Distance and Angle Measuring Equipment (DAME), two-station DME with radar altimeter, and three-station DME.

Since radar and DAME measure position in polar coordinates, a small error in the measured angle can be compounded at a distance to give a large error in spatial position, even though the distance is accurately measured. The DAME is much more accurate since the angle is resolved by an interferometer technique. However, this is also a disadvantage because the long baseline needed between interferometer antennas makes the system bulky and difficult to implement. Additional reasons radar was not selected follow:

(1) Since it is a pulsed device, the minimum range resolution does not meet the requirements of zero-zero landing;

(2) At close range (where the most accurate measurements are required) multipath reflections become extremely critical;

(3) A large ground installation is usually necessary.

Two DME configurations are feasible for zero-zero landing:

(1) Two-station DME and radar altimeter;

(2) Three-station DME, switching to two-station DME and radar altimeter at close ranges.

The first approach, the two-station DME and radar altimeter combination, provides the greatest inherent accuracy in determining position at touchdown. However, this information is only accurate over flat terrain. For a general research program the terrain for a known approach path could be programmed into the computer to correct the measured altitude. This system is considered primarily because of the saving and convenience which would be achieved if one of the DME ground transponders were eliminated.

The second approach, a combination of the three-station DME and a radar altimeter, increases the accuracy in measuring position over rough terrain by using the ranges to the three DME transponders to compute altitude in addition to the ground position of the aircraft. Close to touchdown, where the measurement of altitude deteriorates, the system switches over to the two-station DME and radar altimeter.

The attitude of the aircraft affects the display directly and is not an input for the position computation of the aircraft with respect to the runway. Since the display concept is similar to VFR, the attitude accuracy required is similar to the visual accuracy with which the pilot can sense attitude in a normal landing approach. Another indication of the accuracy requirements is the allowable errors in attitude at touchdown. Attitude errors of 1° are associated with touchdown errors of approximately 6 inches. Therefore, analysis of attitude accuracy requirements indicates that, in general, the electrical pickoffs of a standard aircraft autopilot and the accuracies of its gyros are sufficiently good for the aircraft attitude information.

The output of the position measuring and attitude sensors go to a computer which computes the runway position and attitude with respect to the aircraft. This information then goes to the display generator where it generates a runway display image which is projected directly in front of the pilot. This runway image behaves identically to the real runway as seen through the windshield.

A digital computer will be used in the research program because it can perform logic operations readily, can be easily programmed, and is extremely accurate. These qualities are desirable for studying the zero-zero landing problem for a variety of system concepts. In addition, investigation of many methods of sensing aircraft position and displaying information to the pilot add to the need for versatility provided by the digital computer.

The DME system measures the distance from the aircraft to small transponder units placed on the ground near the runway, as shown in figure 6. The accuracy of DME is increased for long ranges if the baseline distances between transponders are kept large. However, as previously mentioned, zero-zero landing system studies at Ames have shown that while aircraft position must be known accurately at touchdown, this accuracy can deteriorate with distance from touchdown. This enables the baseline of the ground transponders to be reduced so that the transponders can be located near the runway, thus eliminating the problem of accurate location at long baseline distances. Preliminary calculations have shown that the transponders can be located within 250 feet of the runway center line, and still achieve the required position accuracy. Studies are now under way to determine the optimum positioning of these ground transponders; both the ease of placing the transponders and the computed aircraft position error are being considered.

The actual distance from the aircraft to each transponder is measured by radio-frequency methods employing phase comparison techniques which give a very high degree of accuracy. The error in this measurement is constant regardless of the distance measured. The range to all three transponders is measured simultaneously and is read into the computer at a rate high enough to keep the position error within specifications - on the order of 5 times per second. The slant-range data to the transponders, along with the previously stored ground transponder position data, is then used to compute the aircraft's position.

Figure 7 shows the radar altimeter errors near touchdown as a function of the distance from touchdown. In addition to the theoretical errors shown in figure 7, the altitude error increases farther out because of variations in local terrain. On the other hand, if a three-transponder DME configuration is used to compute the three dimensions of position, the altitude error increases as the altitude becomes small near touchdown because of the trigonometric nature of the position solution from the three-station DME configuration. However, farther from touchdown this altitude error tends to level off and changes nearly linearly with distance. Because of these characteristics, it was decided to use a three-station DME to a point near touchdown, switch to a two-station DME mode to obtain plan position, and use a radar altimeter to obtain the critical altitude information near touchdown. This changeover in system mode is made as the error crossover point is reached. In this way, the altitude percentage error is held approximately constant and the system is within the specified accuracies from a distance of 15 miles through touchdown.

In addition to determining altitude above the ground, the radar altimeter can also obtain the three orthogonal components of aircraft velocity using a Doppler measuring technique. Through an antenna servo system used in conjunction with the Doppler system it is possible to determine the aircraft ground speed and drift angles. This information is useful to the pilot in decrab and final touchdown maneuvers.

The Doppler navigation capability of the radar altimeter enables the computer to integrate the ground velocity to determine the distance the aircraft has moved over the ground. If initial conditions of the DME are programmed into the computer, the ground position of the aircraft can be computed from the Doppler information. This redundant computation serves as a check on system performance during the entire landing maneuver.

CONCLUSIONS

Ames studies of zero-zero landing problems have shown that the pilot can function as an integral part of the system. These studies conducted in the simulation laboratory have indicated requirements for displays for zero-zero landing. Ames experience in simulation studies of the aircraft, and the evaluation of engineering test pilot opinion have enabled the extrapolation of these studies into the design of a flying laboratory to permit the study of the zero-zero landing of an actual aircraft.

An airborne guidance system may offer a good potential for use in landing under zero-zero visibility conditions. The accuracy of the combination of a digital computer, radar altimeter, and DME has greater inherent accuracy in determining aircraft position than is required for the task. Although simulation studies have indicated zero-zero landing can be achieved, these results are not conclusive. Actual flight tests in which a research environment is maintained are essential for investigating displays and systems concepts for the task.

REFERENCES

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2. Snodgrass, R. P.: The "Black Hole" in the Cockpit. Sperry Gyroscope Company, Great Neck, New York. Presented at the 13th Annual Technical Conference, International Air Transport Association, May 2-8, 1960, Lucerne, Switzerland.
3. Anon.: Spectocom Head-Up Display. 815/B1, Computing Devices of Canada, Ltd., Ottawa, Ontario, Canada, and Specto Ltd., Windsor, England, April 1962.

DIAGRAM OF ZERO-ZERO LANDING SIMULATOR

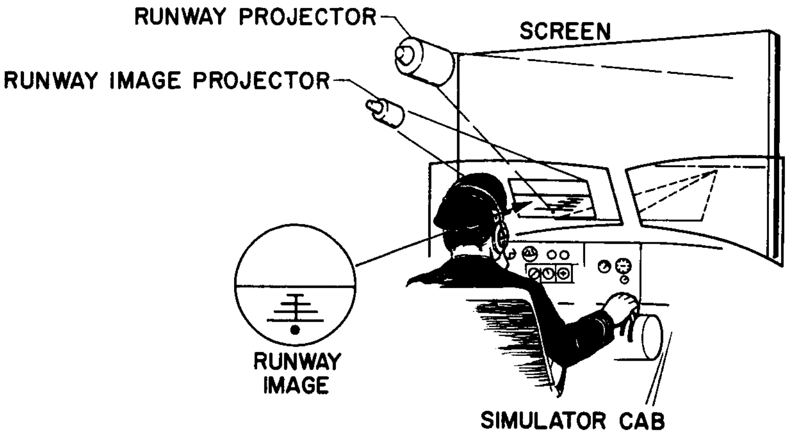

Figure 1.

BASIC GUIDELINES FOR ZERO – ZERO LANDING SYSTEM

1. SYSTEM USES THE LEAST POSSIBLE GROUND EQUIPMENT

2. SYSTEM USES THE AMES CONCEPT OF PILOTS DISPLAY

Figure 2.

ACCURACY OF AIRCRAFT POSITION

ACCURACY AT TOUCHDOWN		ACCURACY DURING APPROACH
SLANT RANGE	± 500 ft	± 10% OF SLANT RANGE OR ± 500 ft, WHICH-EVER IS GREATER
LATERAL DISPLACEMENT	± 25 ft	± 1% OF SLANT RANGE OR ± 25 ft, WHICH-EVER IS GREATER
ALTITUDE	± 5 ft	± 1% OF ELEVATION OR ± 5 ft, WHICH-EVER IS GREATER

Figure 3.

AIRBORNE RESEARCH SYSTEM
FOR ZERO-ZERO LANDING

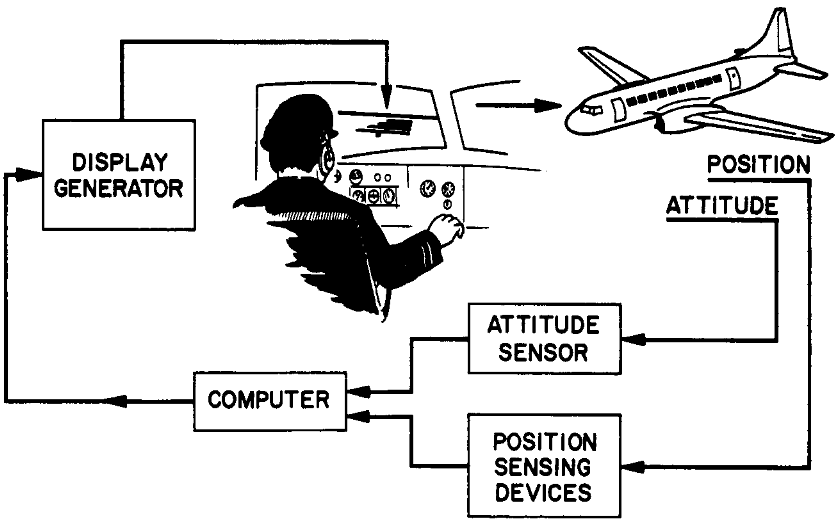

Figure 4.

BLOCK DIAGRAM OF LANDING SYSTEM

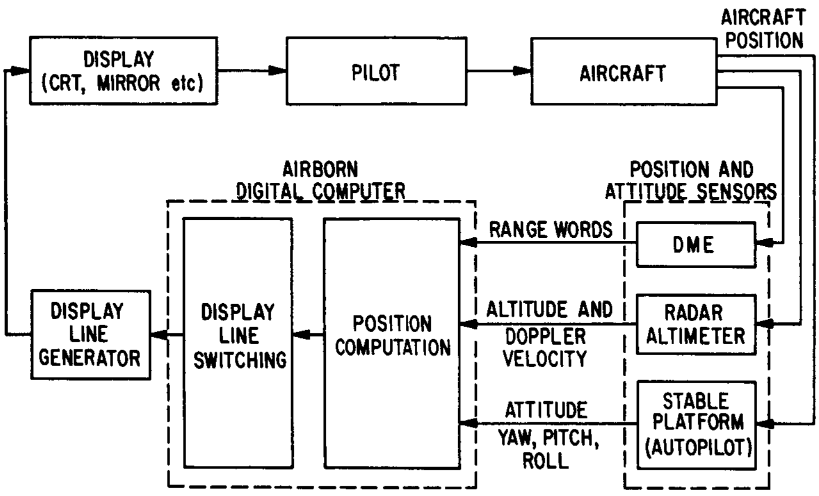

Figure 5.

GROUND TRANSPONDER CONFIGURATION

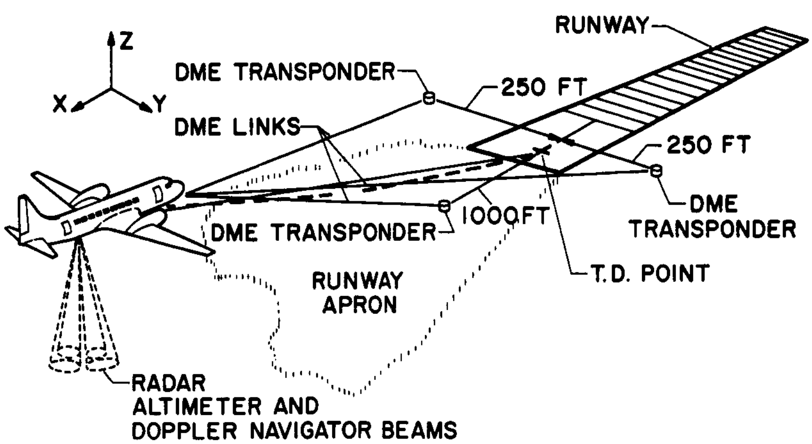

Figure 6.

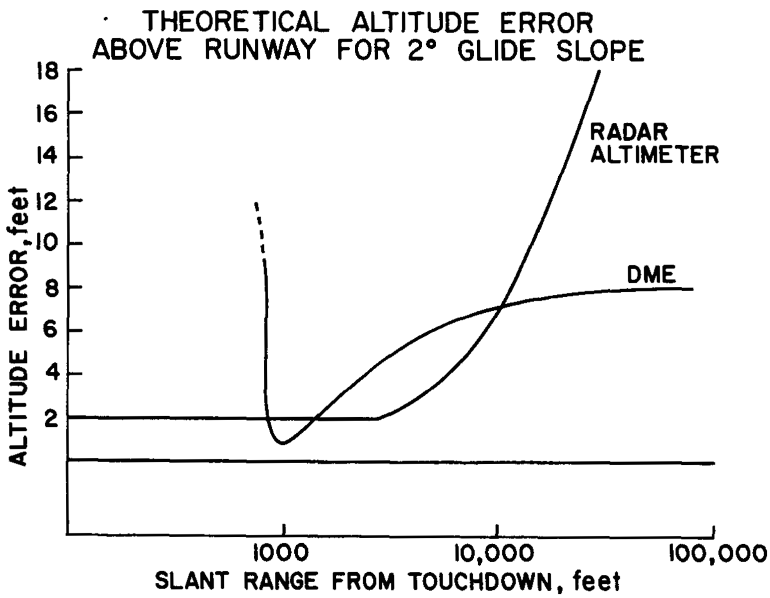
THEORETICAL ALTITUDE ERROR
ABOVE RUNWAY FOR 2° GLIDE SLOPE
ALTITUDE ERROR, feet
18
16
14
12
10
8
6
4
2
RADAR
ALTIMETER
DME
1000
10,000
100,000
SLANT RANGE FROM TOUCHDOWN, feet

Figure 7.